

Polymer Processing for All-Optical Device Fabrication

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FINAL REPORT TO AFOSR

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We have achieved our research goal to study the effect of polymer processing and composition on fabricability and performance of all-optical switching devices and optical amplifier devices. In the process, we have developed a deeper understanding of the linear and nonlinear properties of materials and how they affect device performance.

There are 6 major efforts in the this program. Present experiments in progress include:

- inter-ferometric measurements of the intensity dependent refractive index in single-mode polymer optical fibers
- loss, scattering, fluorescence and two photon absorption measurements based on a new transverse excitation technique that was invented in our laboratory
- refractive index profiling measurement techniques
- third-order susceptibility studies aimed at understanding the nonlinearity mechanisms in dye-doped polymers
- Dual-core single-mode fiber development
- Fibers with electrodes

The interferometric intensity dependent refractive index studies of both bulk and fibers has turned up many interesting results. First, the Sagnac configuration is actually an optical switch, in which we have seen switching efficiencies approaching 100%. Secondly, we have found many nuances in interferometric measurements that show how unreliable they are in bulk measurements (which is the kind of measurement that many researchers use to characterize materials) and how good they are in fiber waveguides. The conclusion is that

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material evaluation studies for making devices should only be performed in fiber waveguide geometries.

The loss, scattering, fluorescence and two photon absorption measurements are based on a new transverse excitation technique where a light source illuminates the fiber from the side. Side illumination results in fluorescence, that propagates down the fiber. As such, it results in a broad spectrum of light that propagates down the fiber, yet insures that most of the laser line does not travel down the fiber. By scanning a detector perpendicular to the fiber along its length, a measure of the scattered spectrum as a function of distance yields the dispersion of the loss in the fiber over a broad color range in the near IR. Intensity dependent measurements, on the other hand, can be used to study isomerization, bleaching, and two-photon absorption.

Note that we have applied the Side-illumination technique, along with a new theory of inhomogeneous broadening, to understanding both the linear and nonlinear spectra of organic molecules. These studies show that many of the past measurements by our group and many others may not be accurate.

We have also completed a series of pump-probe measurements of the ultrafast response of organic molecules to understand whether spectroscopies (such as electroabsorption) can be extrapolated to the ultrafast regime. We have found that both measurements can be predicted by a single unifying theory using inhomogeneous broadening of a multi-level system.

We have either developed or implemented several techniques for measuring the refractive index profile in a preform and fiber. They include the refractive bending method (developed at WSU), the near field refractive technique, and the wiggly beam technique (developed at WSU). The refractive bending technique has the advantage that it can measure the refractive index profile of a preform slice without the need for mathematical assumptions. The wiggly beam technique, on the other hand, is based on a Fresnel factor determination from a reflected beam. Because the beam is swept across the sample surface as a sine function of time, a lock-in amplifier is used to get the reflectance - thereby yielding a much higher sensitivity. The main advantage is that even light absorbing samples can be measured.

The dual-core project has successfully demonstrated a nonlinear coupler, so this objective is complete. We are therefore now focusing efforts to better understand nonlinear-optical mechanisms. These studies will be of utmost importance for the design of commercial devices. Note that we continue processing studies to improve fibers.

PERSONNEL SUPPORTED:

Principal Investigator:

- Mark Kuzyk

Post Doc:

- Youngsoon Baek

- Chris Kwiatkowski

Graduate Students:

- Brian Canfield

- Robert Kruhlak
- Steve Vigil
- Zhongcai Zhou

Undergraduates:

- Chris Breckon
- Michelle Repp
- Jeremy Young

PAPERS AND PRESENTATIONS

Ten refereed papers on AFOSR-supported work appeared in a refereed journal during the report period:

- D. W. Garvey, K. Zimmerman, P. Young, J. Tostenrude, J. S. Townsend, Z. Zhou, M. Lobel, M. Dayton, R. Wittorf, M. G. Kuzyk, J. Sounick, J. Sounick, and C. W. Dirk, "Single-mode nonlinear-optical polymer fiber," *Journal of the Optical Society of America* **13**, 2017 (1996).
- F. Gehbremicahel, M. G. Kuzyk, and H. Lackritz, "Nonlinear Optical and Polymer Physics," *Polymer Reviews* **22**, 1147 (1997).
- Z. Zhou, S. Vigil, B. Canfield, J. Tostenrude, and M. G. Kuzyk, "Dual Core Single-Mode Nonlinear Fiber Coupler," *JOSA B* **15**, 895 (1998).
- K. Mathis, M. G. Kuzyk, and C. W. Dirk, "The Mechanisms of the Nonlinear Optical Properties of Squaraine Dyes in PMMA Polymer, *JOSA B* **15**, 871 (1998).
- F. Ghebremichael, M. G. Kuzyk, K. D. Singer and J. Andrews, "Relationship Between the Second-Order Microscopic and Macroscopic Nonlinear Optical Susceptibilities of Poled Dye-Doped Polymers," *JOSA B* **15**, 2294 (1998).
- J. Welker, J. Tostenrude, D. W. Garvey, B. K. Canfield, and M. G. Kuzyk, "Fabrication and Characterization of Single-Mode Electro-Optic Fiber," *Opt. Lett* **23**, 1826 (1998).
- R. Kruhlak and M. G. Kuzyk, "Side Illumination Fluorescence (SIF) Spectroscopy I: Principals," *JOSA B* **16**, 1749 (1999).
- R. Kruhlak and M. G. Kuzyk, "Side Illumination Fluorescence (SIF) Spectroscopy II: Applications to Squaraine Dye-Doped Polymer Optical Fibers," *JOSA B* **16**, 1756 (1999).
- M. G. Kuzyk, D. W. Garvey, B. K. Canfield, S. Vigil, D. J. Welker, J. Tostenrude, and C. Breckon, "Characterization of Single-Mode Polymer Optical Fiber and Electrooptic Devices," *Chemical Physics* **245**, 327 (1999).
- M. G. Kuzyk, D. W. Garvey, S. Vigil, and D. J. Welker, "All-Optical Devices in Polymer Optical Fiber," *Chemical Physics* **245**, 533 (1999).

Books

Mark G. Kuzyk and C. W. Dirk, "Measurement Techniques and Tabulations For Organic Nonlinear Optical Materials," Marcel Dekker, New York (1998). Note that this book had lots of new material not before published.

Presentations

- M. G. Kuzyk, B. K. Canfield, D. W. Garvey, J. A. Tostenrude, S. R. Vigil, J. E. Young, Z. Zhou, and C. W. Dirk, "Polymer fibers as optical device components," page 422 in Sol-Gel and Photonic Devices, M. P. Andrew and S. I. Naafi, eds., SPIED CRT **68** (1997). - **Invited**
- M. G. Kuzyk, "Linear and nonlinear polymer optical fiber devices," POF'97, Kauai (1997). - **Invited**
- M. G. Kuzyk, D. J. Welker, J. A. Tostenrude, B. K. Canfield "Electrooptic fiber devices," POF'98, Berlin (1998). - **Invited**
- M. G. Kuzyk, D. J. Welker, J. A. Tostenrude, B. K. Canfield "All-Optical and Electrooptical Fiber," ICONO'4, Chitose (1998). - **Invited**
- D. W. Garvey and M. G. Kuzyk, "Nonlinear Optics of Polymer Optical Fibers," SPIE Proc. **3796**, San Diego (1999). - **Invited**
- D. J. Welker, D. W. Garvey, C. D. Breckon, B. K. Canfield, and M. G. Kuzyk, "Single-Mode Nonlinear Electrooptic Polymer Optical Fiber," POF World '99, **23** (1999). - **Invited**
- D. J. Welker, D. W. Garvey, C. D. Breckon, and M. G. Kuzyk, "Advances in Electrooptic Fiber Devices," ACS OSA Thin Films Meeting, Santa Clara (1999). - **Invited**
- M. G. Kuzyk, "Quantum Limits on Nonlinear Susceptibilities," ICONO'5, Switzerland (2000). - **Invited**
- Y. Baek, G. I. Stegeman, D. W. Garvey, and M. G. Kuzyk, "Third-order Nonlinearity Measurements in Dye-Doped Fiber at 1.32 Micron," ICONO'3, Marco Island (1996).
- K. Mathis, M. G. Kuzyk, C. W. Dirk, S. Martinez, H. Selnau, Jr., P. Craig, and L. Green, "Essential State Analysis of Squaraines Using Quadratic Electroabsorption," ICONO'3, Marco Island (1996).
- R. Kruhlak, J. E. Young, and M. G. Kuzyk, "Loss measurements in squaraine-doped nonlinear polymer optical fibers," Proc. SPIE **3147**, 18 (1997).
- B. K. Canfield, D. W. Garvey, J. E. Young, and M. G. Kuzyk, "Refractive index profiles of polymer optical fibers," Proc. SPIE **3147**, 128 (1997).

- D. W. Garvey, and M. G. Kuzyk, and C. W. Dirk "Measurements of the real and imaginary parts of gamma for four squaraine dye molecules in a PMMA host," Proc. SPIE **3147**, (1997).
- S. R. Vigil, Z. Zhou, and M. G. Kuzyk, "Intensity-dependent coupling in dual-core nonlinear polymer optical fiber," Proc. SPIE **3147**, 237 (1997).
- R. Kruhlak and M. G. Kuzyk, "Loss spectroscopy through side-illumination Fluorescence in dye-doped polymer optical fibers," Proc. SPIE **3473**, (1998).
- B. K. Canfield, S. R. Vigil, and M. G. Kuzyk, "Refractive and bandwidth measurements of polymer optical fibers," Proc. SPIE **3473**, (1998).
- D. M. Sullivan and M. G. Kuzyk, "Three-Dimensional Nonlinear Optical Fiber Simulation," Proc. SPIE **3465**, 134 (1998).
- I. Cokgor, A. S. Dvornikov, R. Piyaket, S. C. Esener, P. M. Rentzepis, D. W. Garvey, and M. G. Kuzyk, "Spyrobenzopyran doped core PMMA fibers," Proc. SPIE Photonics West'99 (1998).
- B. K. Canfield and M. G. Kuzyk "Refractive Index Profiling Methods for Polymer Optical Fiber Preforms and Fibers," ICONO'4 (1998).
- D. M. Sullivan, J. Liu, and M. G. Kuzyk, "Three-Dimensional Optical Fiber Simulation," IEEE Inter. Symp. and USNG/URSI National Radio Meeting, Orlando, FL, July 11-16 (1999).
- S. R. Vigil and M. G. Kuzyk, "Optical Kerr Effect Measurements of Methyl Methacrylate/Nitrobenzene Solutions," Proc. SPIE **623** (1999).
- R. J. Kruhlak and M. G. Kuzyk, "Side Illumination Fluorescence (SIF) Spectroscopy Studies of Aggregation in ISQ Dye-Doped Polymer Optical Fibers," Proc. SPIE **3799** (1999).
- B. K. Canfield, M. G. Kuzyk, and D. J. Welker "Nonlinear Optical Characterization of Polymer Electrooptic Fiber," Proc. SPIE **3796** (1999).
- B. K. Canfield and M. G. Kuzyk "Refractive Index Profiling Methods for Polymer Optical Fiber Preforms and Fibers," Northwest Regional Meeting of the APS (1999).
- R. J. Kruhlak, M. C. Repp, and M. G. Kuzyk "Side Illumination Fluorescence (SIF) Measurements of Dye-Doped Polymer Optical Fibers," Northwest Regional Meeting of the APS (1999).
- R. J. Kruhlak and M. G. Kuzyk, "Photosensitivity of Squaraine Dye-Doped Polymer Optical Fiber using Side-Illumination Fluorescence(SIF)," Opto Northwest (1999).
- B. K. Canfield, R. J. Kruhlak, and M. G. Kuzyk "Investigation of the Third-Order Optical Susceptibility of Chromophores Through Broadband Electronic Spectroscopy," ICONO'5, Davos, Switzerland (2000).

- R. J. Kruhlak and M. G. Kuzyk “Determining the nature of Excited States Using and Inhomogeneous-Broadening Analysis of Third-Order Processes,” ICONO’5, Davos, Switzerland (2000).

DEGREES

Dennis Garvey, Ph.D. 1999

Thomas Wofford, M.S. 2000

Robert Kruhlak, Ph.D. 2000

TRANSITIONS

a. M. G. Kuzyk / Washington State University, b. Processing for making polymer fibers without banding, c. Transition to Boston Optical Fiber, Victor Ilyanshenko, 508-836-2700, d. Manufacturing of graded index polymer optical fibers.

a. M. G. Kuzyk / Washington State University, b. Refractive index characterization of preforms, c. Transition to Boston Optical Fiber, Victor Ilyanshenko, 508-836-2700, d. Used to improve materials processing to make better graded index polymer optical fibers.

a. M. G. Kuzyk / Washington State University, b. Single-mode Polymer Fiber Fabrication, c. Transition to Sentel Technologies, LLC, David Welker, 509-334-5190, d. Manufacturing of specialty polymer optical fibers (please see <http://www.senteltech.com>).

In addition to our ongoing collaborations, we have been collaborating with Prof. Singer at Case Western and Dr. Trupp (using fibers for shock physics experiments) at Los Alamos.

REPORT DOCUMENTATION PAGE

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